

From deep-inelastic structure functions to two-photon dilepton production in proton-proton collisions

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We compare two different approaches used for calculating cross sections for the two-photon $pp \rightarrow l^+l^-X$ process. In one of the approaches photon is treated as a collinear parton in the proton. In the second approach a recently proposed k_T -factorization method is used. In this presentation we discuss sensitivity of the results to the choice of structure function parametrization and experimental cuts in the k_T -factorization approach. We compare results of our calculations with recent experimental data for dilepton production and find that in most cases the contribution of the photon-photon mechanism is rather small. We discuss how to enhance the photon-photon contribution. We also compare our results to those of recent measurements of exclusive and semi-exclusive e^+e^- pair production with certain experimental data by the CMS collaboration.

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1. Introduction

In this presentation we show our recent results published in [1] where we have considered $pp \rightarrow pp l^+ l^-$ (exclusive) and $pp \rightarrow l^+ l^-$ (semiexclusive, with proton dissociation) double photon fusion processes in the proposed somewhat earlier k_t -factorization approach [2]. In our presentation at DIS2016 we have focussed on the relation of the cross section for the charged lepton pair production with the dependence of the deep-inelastic structure functions F_2 , that are the input for our approach, on x and Q^2 .

The main mechanisms of the dilepton production considered in [1] are shown in Fig.1. The considered mechanism has the same final state as the dominant Drell-Yan mechanism. For k_t -factorization approach to the Drell-Yan see [3, 4, 5, 6]. In our recent paper [1] we discussed in detail the photon-photon mechanism.

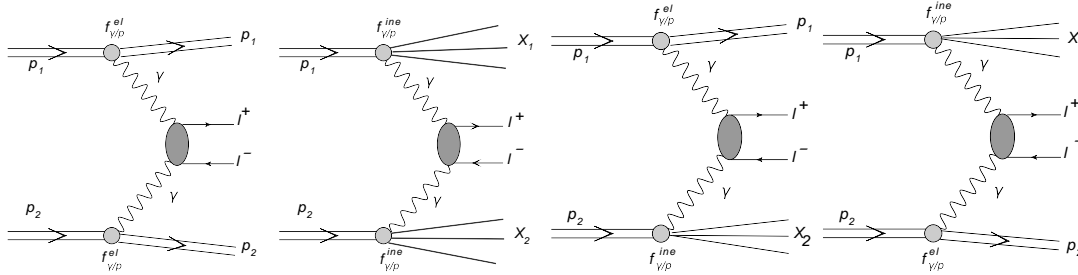


Figure 1:

Different mechanisms of two-photon production of dileptons included in [1].

2. Basic formulae

In collinear approximation the cross sections are calculated as:

$$\frac{d\sigma^{\gamma_{in}\gamma_{in}}}{dy_1 dy_2 d^2 p_t} = \frac{1}{16\pi^2 s^2} x_1 \gamma_i(x_1, \mu^2) x_2 \gamma_j(x_2, \mu^2) |\overline{\mathcal{M}_{\gamma\gamma \rightarrow l^+ l^-}}|^2, \quad (2.1)$$

where $i,j=el,in$ and f_i are photon PDFs. The elastic photon fluxes are calculated using the Drees-Zeppenfeld parametrization, where a simple parametrization of nucleon electromagnetic form factors was used.

In the k_t -factorization approach the differential cross section can be written as:

$$\frac{d\sigma^{(i,j)}}{dy_1 dy_2 d^2 p_1 d^2 p_2} = \int \frac{d^2 q_1}{\pi q_1^2} \frac{d^2 q_2}{\pi q_2^2} \mathcal{F}_{\gamma^*/A}^{(i)}(x_1, q_1) \mathcal{F}_{\gamma^*/B}^{(j)}(x_2, q_2) \frac{d\sigma^*(p_1, p_2; q_1, q_2)}{dy_1 dy_2 d^2 p_1 d^2 p_2}, \quad (2.2)$$

where $i,j=el,ine$ and \mathcal{F}_k are unintegrated fluxes of photons. As shown in [1] the unintegrated fluxes can be expressed in terms of the (deep-inelastic) structure functions $F_2(x, Q^2)$.

3. Numerical results

In our studies in [1] we have used a few different parametrizations of the proton structure function F_2 taken from the literature:

- ALLM [8, 9]. This parametrization gives a very good fit to F_2 in most of the measured region.
- FJLLM [10]. This parametrization explicitly includes the nucleon resonances and gives an excellent fit of the CLAS data.
- BDH [11]. This parametrization concentrates on the low- x , or high mass region. It features a Froissart-like behaviour at very small x .
- SY [12]. This parametrization of Suri and Yennie from the early 1970's does not include QCD-DGLAP evolution. It is still today often used as one of the defaults in the LPAIR event generator.
- SU [13]. A parametrization which concentrates to give a good description at rather small and intermediate Q^2 at not too small x .

We also show F_2 calculated from the CTEQ6L parametrization [14].

In Fig.2 we show only two examples of the proton structure function $F_2(x, Q^2)$ obtained from the various parametrizations at $Q^2 = 2.5, 4.5 \text{ GeV}^2$ as a function of Bjorken- x .

It is surprising that the old Suri-Yennie [12] fit, still gives a reasonable description of F_2 except of very small x . For explicit account of resonances we recommend to use the Fiore et al. [10], but care has to be taken to stay within the resonance region, as the quality of the fit beyond this region quickly deteriorates. The overall best description appears to be given by the ALLM [8, 9] fit.

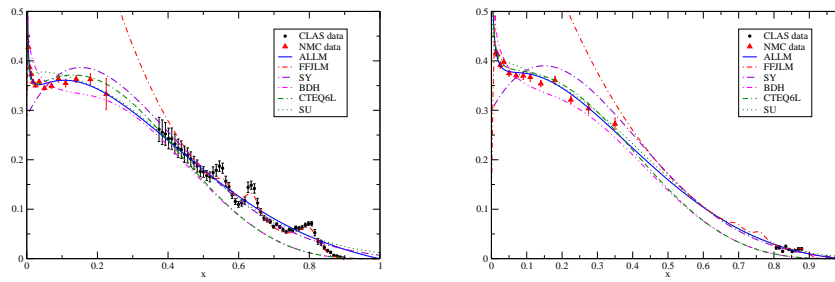


Figure 2: The proton structure function $F_2(x, Q^2)$ as a function of x for $Q^2 = 2.5 \text{ GeV}^2$ (left), and $Q^2 = 4.5 \text{ GeV}^2$ (right). Shown are results for different parametrizations available in the literature.

In Ref.[1] we have compared our calculations with measured dilepton data [15, 16, 17, 18, 19]. Here we show only a few examples.

Most of the experiments for the dilepton production concentrate on determination of dilepton invariant mass distributions. In Fig.3 we show invariant mass distributions of dilepton pairs produced in the photon-photon inelastic-inelastic mechanism for kinematical conditions relevant for

different experiments. We show results obtained with the different parametrizations of the structure functions known from the literature. Surprisingly the different structure functions give quite different results. For completeness in some cases we also show the result obtained in the collinear approach with the MRST2004(QED) photon distribution [7] with (solid black line) and similar one when ignoring the initial input (long-dashed black line). The result obtained within the collinear approach with the MRST2004(QED) distribution is much above the results obtained within the k_T -factorization approach. In our opinion this is mainly related to the large input photon distribution at the initial scale $Q_0^2 = 2 \text{ GeV}^2$. If the input is discarded (long-dashed black line) the collinear result is similar to the results obtained within the k_T -factorization. The inelastic-inelastic contribution gives only a small fraction of the measured cross section for most experimental conditions (ATLAS,LHCb).

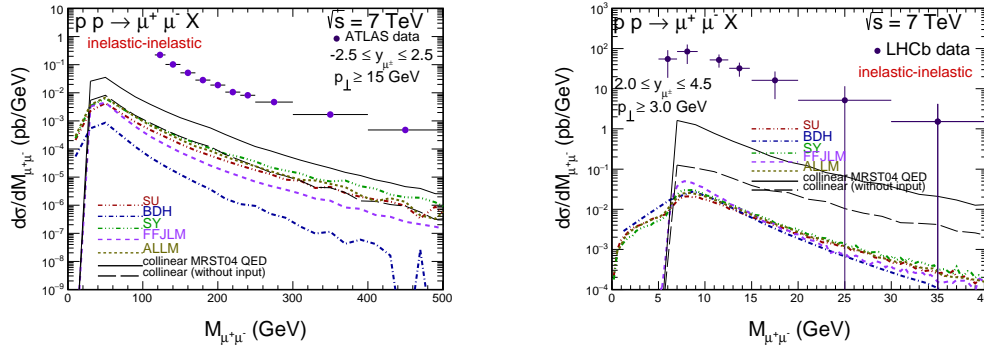


Figure 3: The inelastic-inelastic contribution to dilepton invariant mass distributions for ATLAS (left) and LHCb (right) experiments for different structure functions.

In Fig.4 we show dilepton invariant mass distributions for elastic-inelastic and inelastic-elastic (added together) contributions. As for inelastic-inelastic contribution the results strongly depend on the parametrization of the structure functions used. The spread of results for different F_2 from the literature is now somewhat smaller than in the case of inelastic-inelastic contributions where the structure functions enter twice. As for the double inelastic case we also show a result for the collinear approach. The mixed components give similar contribution to the dilepton invariant mass distributions as the inelastic-inelastic one.

In most of the cases considered so far Drell-Yan processes dominate [4, 5, 6]. The two-photon processes are interesting by themselves. Can they be measured? In order to reduce the Drell-Yan contribution and relatively enhance the two-photon contribution one can impose an extra condition on lepton isolation. First trials have been done by the CMS collaboration [20]. In their analysis an extra lepton isolation cuts were imposed in order to eliminate the dominating Drell-Yan component. In Figs. 5,6,7 we show our results for two different (SY and ALLM) parametrizations of the structure functions for distributions in dimuon invariant mass, in transverse momentum of the pair and in relative azimuthal angle between $\mu^+\mu^-$. SY and ALLM parametrizations give almost the same contributions to all the distributions considered. In the first evaluation we have taken into account integrated luminosity of the experiment ($L = 63.2 \text{ pb}^{-1}$) as well as experimental acceptances given in Ref.[20]. Rather good agreement with the low statistics CMS experimental data is achieved without including any extra corrections due to absorption effects. It may mean that

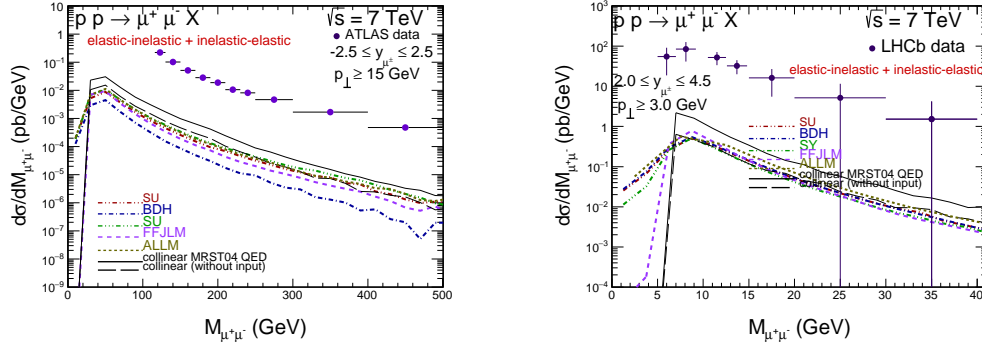


Figure 4: The (elastic-inelastic)+(inelastic-elastic) contribution to dilepton invariant mass distributions for ATLAS (left) and LHCb (right) experiments for different structure functions.

the absorption effects are small or alternatively that a contamination of the Drell-Yan contribution is still not completely removed. Both effects should be therefore studied in detail in a future.

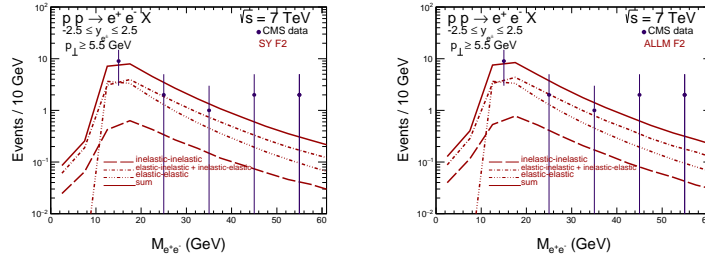


Figure 5: Number of events per invariant mass interval for the CMS experimental cuts for SY (left) and ALLM (right) structure functions. The experimental data points are from Ref.[20].

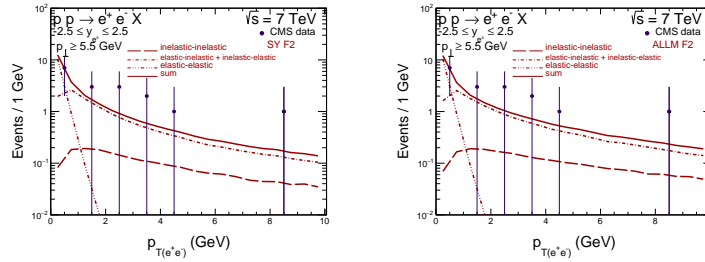


Figure 6: Number of events per pair transverse momentum interval for the CMS experimental cuts for SY (left) and ALLM (right) structure functions. The experimental data points are from Ref.[20].

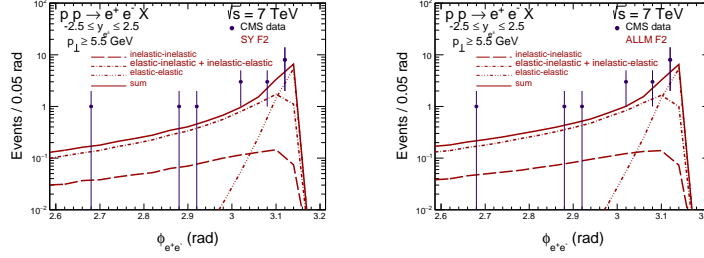


Figure 7: Number of events per pair relative azimuthal angle interval for the CMS experimental cut for SY (left) and ALLM (right) structure functions. The experimental data points are from Ref.[20].

4. Conclusions

We summarize our studies in [1] as follows:

- Two different approaches (collinear and k_t -factorization) for $\gamma\gamma \rightarrow l^+l^-$ processes were discussed and compared.
- Strong dependence on the structure function input in the k_t -factorization approach were found.
- Semi-exclusive contributions with proton dissociation is large (this may be interesting lesson for other processes such as e.g. the $pp \rightarrow ppJ/\psi$ reaction).
- Photon-photon contribution is rather small compared to Drell-Yan contribution but is important in precision calculations.
- Reasonable description of the CMS data with isolated electrons was achieved (recently also ATLAS obtained similar result).
- The regions of the arguments of the structure function F_2 important for the discussed $\gamma\gamma \rightarrow l^+l^-$ process was identified.
- So far only collinear approach was applied to $pp \rightarrow (\gamma\gamma) \rightarrow W^+W^-XY$ processes which is important in searches for Beyond Standard Model effects.

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